§2. Design and Optimization of High Tc Superconductors for Current Lead Application

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High temperature superconductors (HTS) can be synthesized by the diffusion process between the two components in an appreciably shorter reaction time than that of the HTS prepared by the conventional sintering process. In the Bi-Sr-Ca-Cu-O system, a homogeneous HTS layer of $Bi_2Sr_2CaCu_2O_{8+X}$ (Bi2212) is easily synthesized by the diffusion reaction between Bi-free Sr-Ca-Cu oxide substrate and Bi-Cu oxide coating [1]. In the present study, the transport current performance and heat loads of Bi2212 HTS conical tubular bulk will be reported. The conical shaped tube may be expected to yield larger transport current due to the larger cross-sectional area at warm joint and smaller heat leakage due to the smaller cross-sectional area at cold joint in comparison with the cylindrical tubes. The Bi2212 HTS conical tubes by the diffusion process are attractive for current lead applications in superconducting magnet systems [2) - 4)].

Fig. 1 shows the Bi2212 HTS conical tube specimen 47/39 mm in outside/inside diameter at the larger end, 27/19 mm in outside/inside diameter at the smaller end and 200 mm in length. The Ag contact joints of 100 μm in thickness are formed around both ends of the specimens. One of the advantages in diffusion process enables to form HTS diffusion layer on substrates of any shape.

Fig. 2 shows the test set-up of the Bi2212 conical tube specimen connected to the Cu bus bar and NbTi superconducting wires. The conical specimen is soldered to both Cu end caps using commercial Sn-Pb solder. Seven voltage taps were attached on the upper and lower Cu cap (V1 and V5), outer HTS surface (V2, V3 and V4) and inner HTS surface (V6 and V7), respectively. Five Platinum-Cobalt resistance thermometers were attached to the upper and lower Cu cap (T1 and T5), and to the HTS (T2, T3 and T4). A pair of SUS304 stainless steel boards serves as a shunt, and relieves thermal stress in the specimen. Resistive heaters were installed on the upper Cu cap to adjust the temperature of the larger end of the conical specimen. Then, the specimen was cooled using liquid helium in a cryostat.

The transport current for the conical tube decreases with increasing temperature at the warm joint, and is about 5,000 A at 40 K and 4,000 A at 50 K, which corresponds to the current density of 12,500 A/cm^2 and 10,000 A/cm^2, respectively. Fig. 3 shows the transport performance for the conical tube specimen at the warm joint of 50 K and 55 K, respectively. The transport current of 2,000 A was stably run with no voltage on the HTS part (between V2 and V4). The voltage of the warm joint increased with increasing transport current, and were 800 μV at 50 K and 1,100 μV at 55 K after reaching 2,000 A. On the other hand, both voltages of cold joint at 4.2 K remained approximately constant at 45 μV after reaching 2,000 A. Therefore, the Joule heat generated by transport current of 2,000 A are as small as 90 mW at the cold joint.

The heat leakage conducted through the specimen increases with increasing temperature at the warm joint, that is, the temperature difference between the warm and the cold joint. The heat leakage for the conical tube is calculated to decrease by 30% compared to that of the cylindrical tube with the same cross-sectional area at the warm joint. Present Pb-free Bi2212 conical tubes seem to be promising as large transport current leads with small heat loads for superconducting magnets.

Fig. 1. Bi2212 HTS conical tubular conductor with Ag contact joint on both ends.

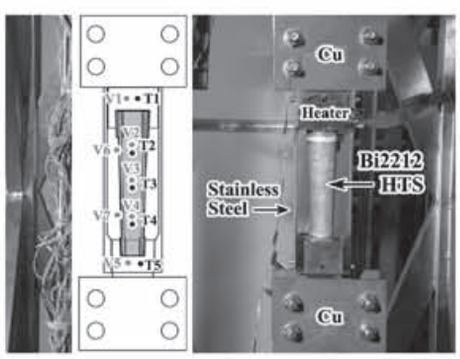

Fig. 2. Test set-up of the Bi2212 conical tube connected to Cu end caps, bus bar and NbTi superconducting wires.

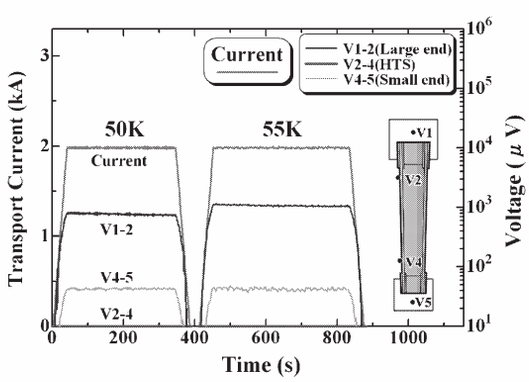

Fig. 3. Transport current performance and voltages of the Bi2212 HTS conical tube at 50 K and 55 K in self-field.

References
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